Sandia National Laboratories

Defining and Measuring Supercomputer Reliability, Availability, and Serviceability (RAS)

Jon Stearley

<jrstear@sandia.gov>

Sandia National Laboratories

June 29, 2005

DARPA HPCS Team&PI Meeting

Reston, VA

See http://www.cs.sandia.gov/~jrstear/ras/

Outline

Sandia National Laboratories

Current practice: Culture problem!
inconsistent terms and metrics
= confusing and costly!

Proposal: Catalyze standardization!
consistent terms, and metrics
= clear, and comparable!

See http://www.cs.sandia.gov/~jrstear/ras/

Confusing! Procurements

Sandia National Laboratories

"Failure of single component will not cause the full system to become unavailable…"

(Red Storm, Purple, Thunder, Q)

"MTBI for full system shall be greater than 50 hours... for a single application"

"MTBI for full system (reboot) shall be greater than 100 hours…"

(over how many samples?) **(Red Storm)**

"100 hour capability jobs (90% of system) will successfully complete 95% of the time…" **(= 79 days of failure-free computing?)**

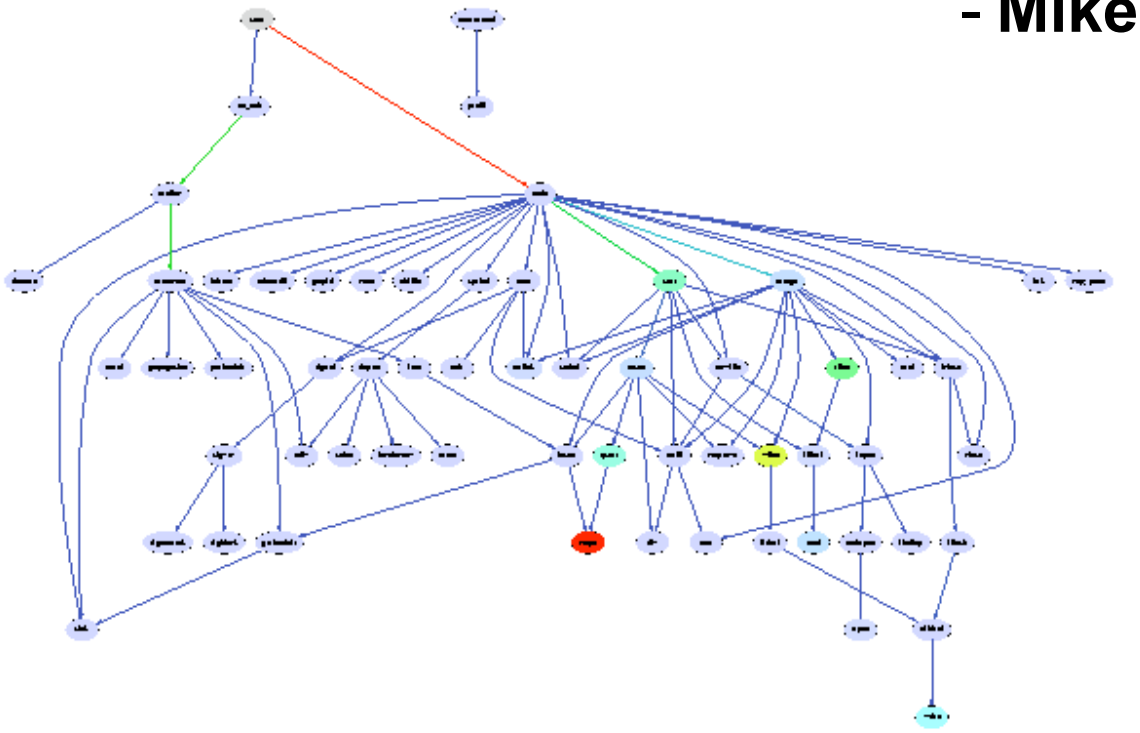
"Over any 4 week period, the system will have an effectiveness level of at least 95%..." **(Purple)**

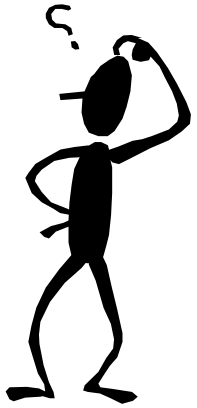
See http://www.cs.sandia.gov/~jrstear/ras/

Confusing!
Operations

"A computer is in one of two situations. It is either known to be bad or it is in an unknown state."

- Mike Levine (PSC)





Is the "system" "up" (yet)?

See http://www.cs.sandia.gov/~jrstear/ras/

Confusing!
Comparisons

Sandia National Laboratories

Systems	CPUs	Reliability & Availability
ASCI Q	**8,192**	**MTBI: 6.5 hrs.** 114 unplanned outages/month. ◆ HW outage sources: storage, CPU, memory.
ASCI White	**8,192**	**MTBF: 5 hrs. (2001) and 40 hrs. (2003).** ◆ HW outage sources: storage, CPU, 3rd-party HW.
NERSC Seaborg	**6,656**	**MTBI: 14 days. MTTR: 3.3 hrs.** ◆ SW is the main outage source. **Availability: 98.74%.**
PSC Lemieux	**3,016**	**MTBI: 9.7 hrs.** **Availability: 98.33%.**
Google	**~15,000**	**20 reboots/day; 2-3% machines replaced/year.** ◆ HW outage sources: storage, memory. **Availability: ~100%.**

MTBI: mean time between interrupts; MTBF: mean time between failures; MTTR: mean time to restore

Source: Daniel A. Reed, UNC (via Chung-Hsing Hsu, LANL)

Costly!
Expensive systems! Poor RAS?

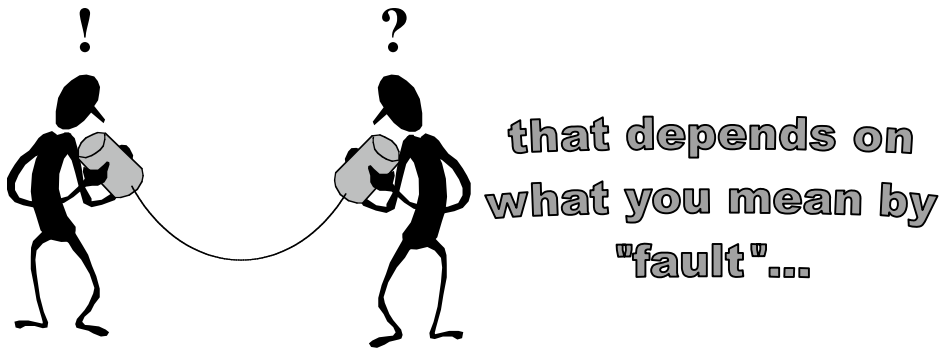
Sandia National Laboratories

Inconsistent terms and metrics

- **Increases costs**
  (in all phases: procurement, operation, retirement)
- **Obscures meaningful discussion of the real issues**
- **Delays real improvements**

Which of the below best characterizes your experience?

My supercomputer is SO RELIABLE!!!



See http://www.cs.sandia.gov/~jrstear/ras/

Needed:
Culture change!

Sandia National Laboratories

Supercomputer RAS is a (hard) technical problem, to which culture-change is a pre-requisite.

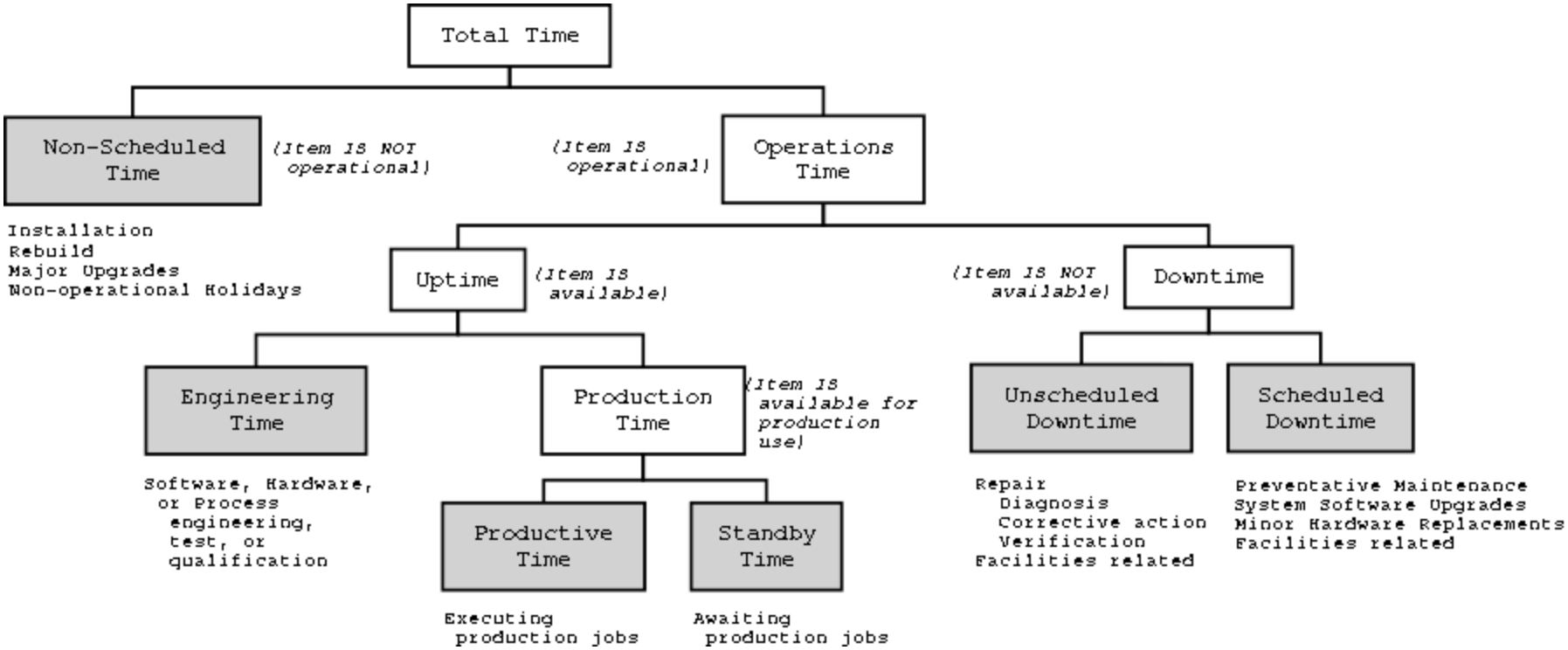
Approach:

- **survey existing HPC best-practices**
- **learn from reliability-savvy communities (e.g. IEEE and manufacturing)**
- **select what is truly useful to improve RAS**

See http://www.cs.sandia.gov/~jrstear/ras/

State Model
(adapted from SEMI-E10)

- **Items are *always* in one of the six basic states (shaded).**
- **Time is hierarchically categorized (white).**



See http://www.cs.sandia.gov/~jrstear/ras/

Cause vs Effect: Failure vs Interrupt

Sandia National Laboratories

Failure – the termination of the ability of an item to perform a required function. [IEEE]

External corrective action is required into order to restore this ability (e.g. manual reboot, repair, replacement). [LLNL]

Interrupt – the suspension of a process to handle an event external to the process. [ISO9000]

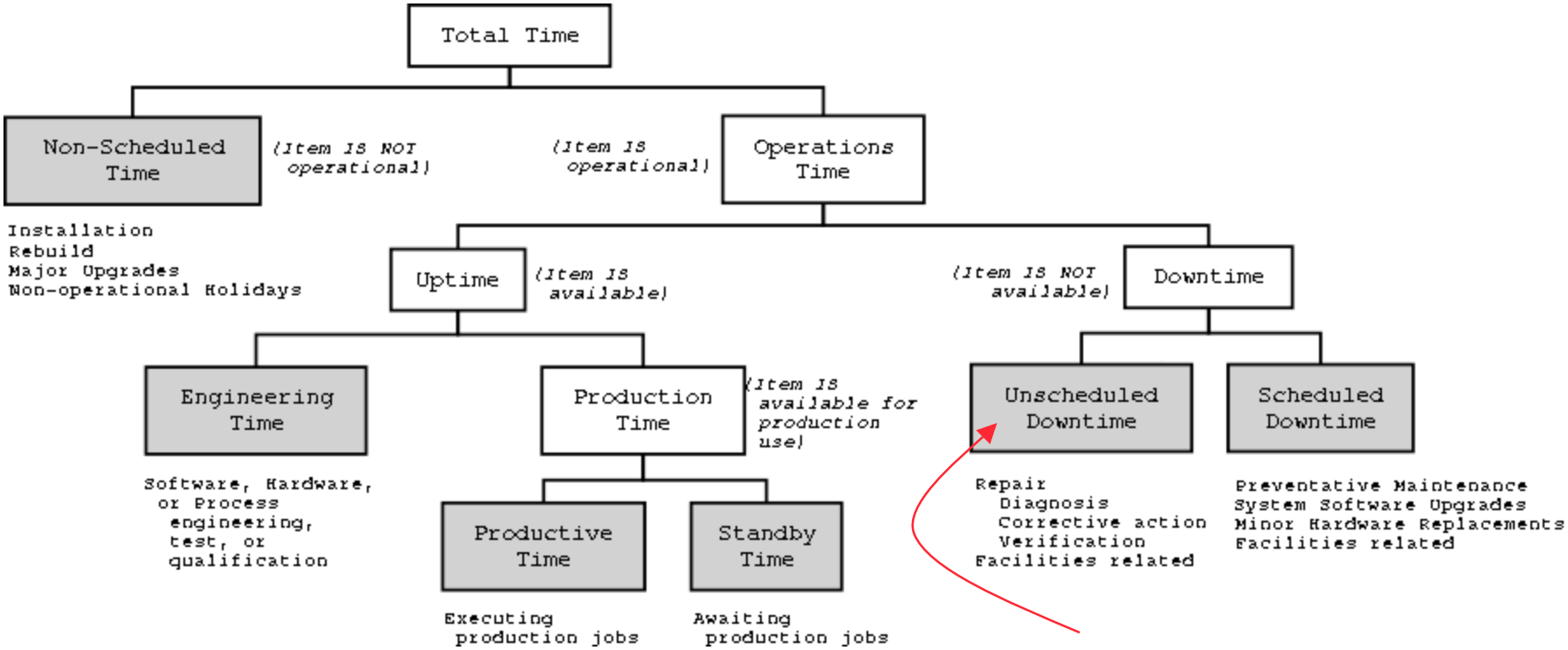
Failures regard items; interrupts regard work.
Failures *may* cause interrupts.

See http://www.cs.sandia.gov/~jrstear/ras/

State Model
(adapted from SEMI-E10)

Sandia National Laboratories

A general model, with platform-specific details.



"failure" = ANY transition into Unscheduled Downtime

See http://www.cs.sandia.gov/~jrstear/ras/

Mean Time Between Job Interrupts

Common:

$$MTBI = \frac{total\ time}{number\ of\ interrupts}$$

Easy to calculate
(but assumes downtime is negligible)

Proposed:

Job Interrupt - The unexpected interruption of an active job.

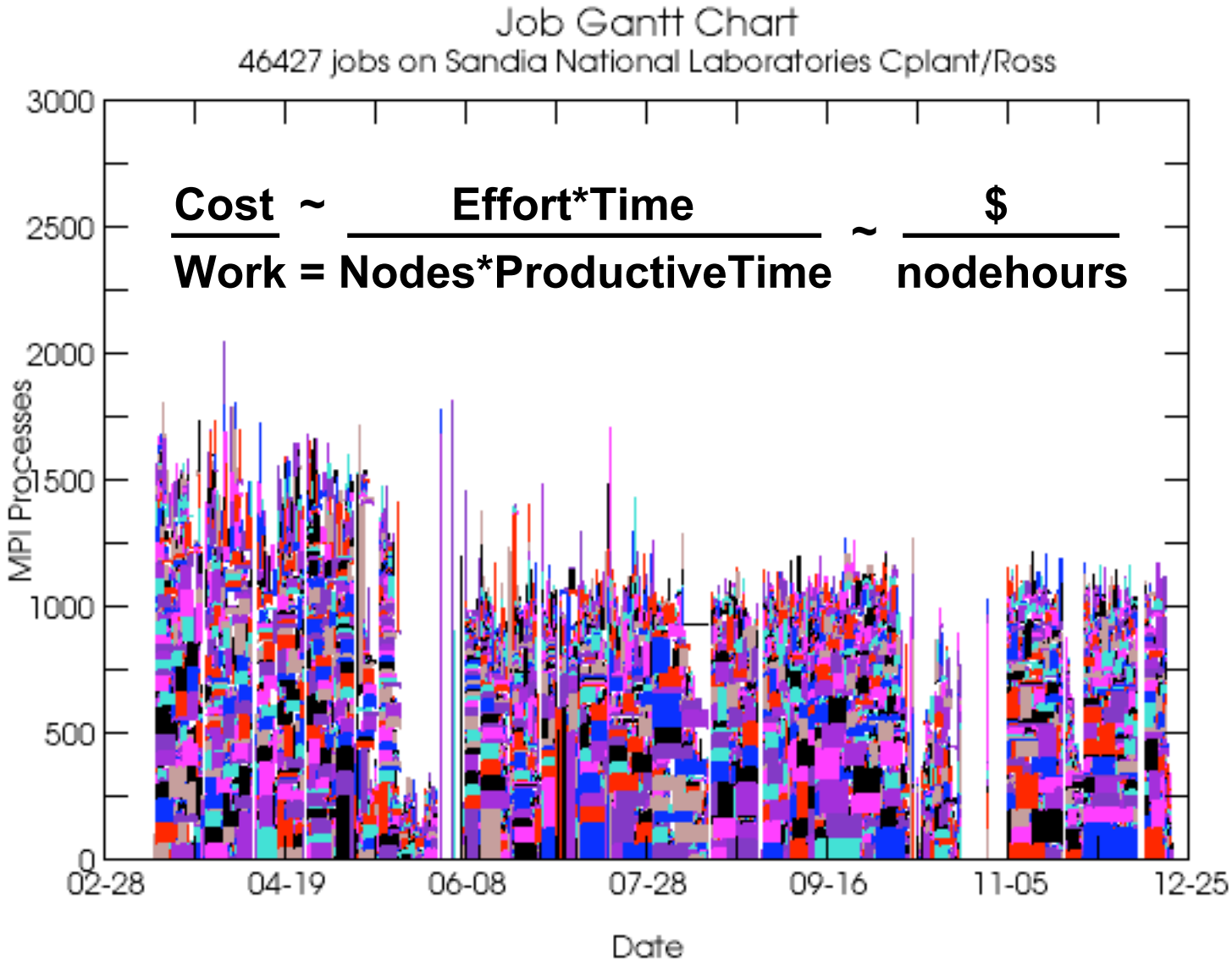
$$MTBI_{Job} = \frac{production\ \ time}{number\ of\ \ job\ interrupts}$$

More precise

More specific

However - interrupts regard work,
and the above contains no work information.

Workload information is vital!



$$\frac{\text{Cost}}{\text{Work = Nodes*ProductiveTime}} \sim \frac{\text{Effort*Time}}{} \sim \frac{\$}{\text{nodehours}}$$

Mean Time Between Job Interrupts

Common:

$$MTBI = \frac{total\ time}{number\ of\ interrupts}$$

Easy to calculate
(but assumes downtime is negligible)

Proposed:

Job Interrupt - The unexpected interruption of an active job.

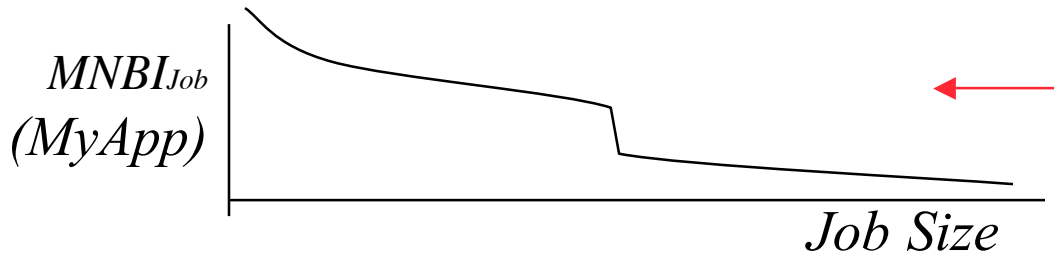
$$MTBI_{Job} = \frac{production\ \ time}{number\ of\ \ job\ interrupts}$$

More precise (but no work info)

More specific

$$MNBI_{Job} = \frac{productive\ \ nodehours}{number\ of\ \ job\ interrupts}$$

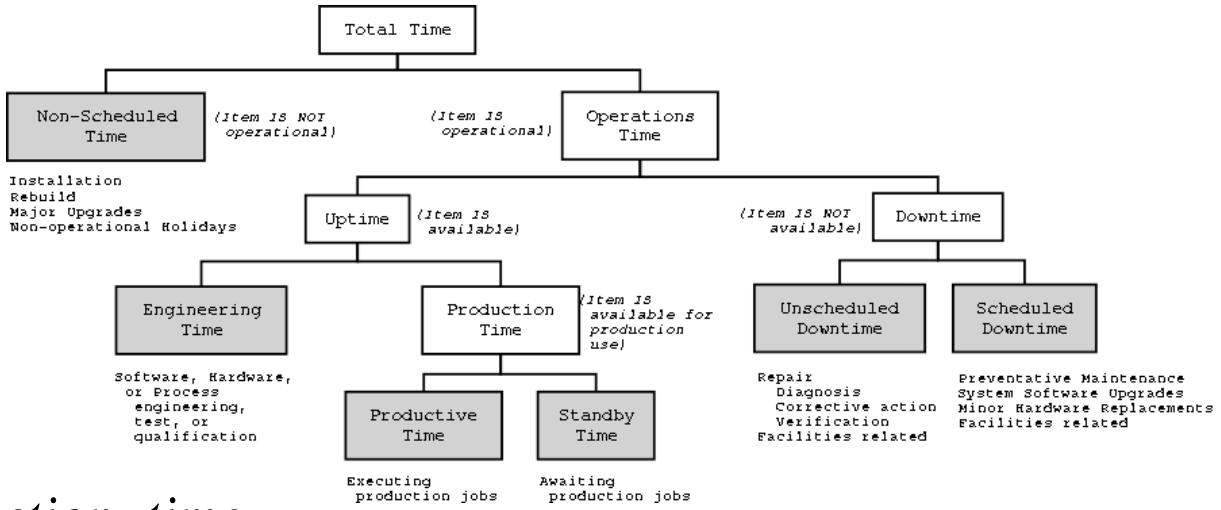
Includes workload information



A conceptual reliability characteristics plot (reliability as a function of job size).

Mean Time Between System Failures

System Failure – an event requiring that the system (the majority of components) enter a downtime status before any component may enter a productive status.



$$MTBF_{System} = \frac{production\ \ time}{number\ of\ system\ \ failures}$$

$$MNBF_{System} = \frac{productive\ \ nodehours}{number\ of\ system\ \ failures}$$

← Includes workload information

See http://www.cs.sandia.gov/~jrstear/ras/

Reliability [IEEE]

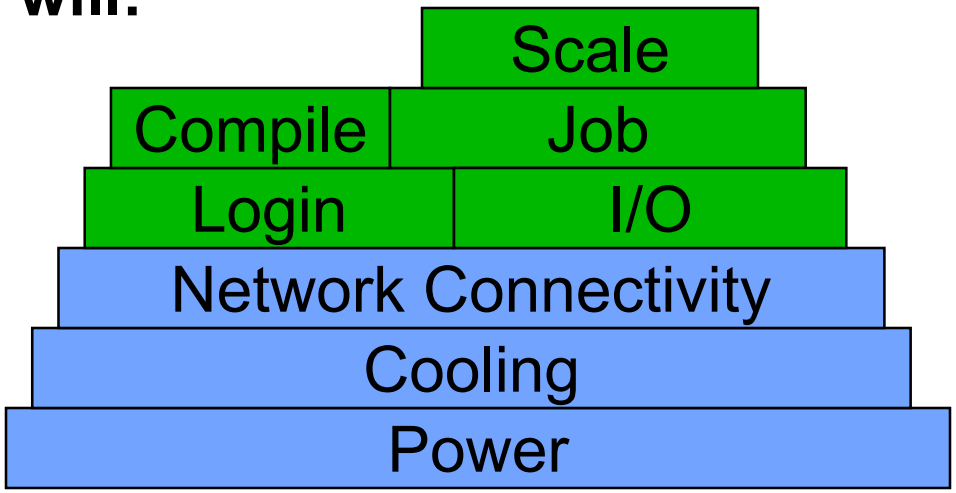
Sandia National Laboratories

The probability that an *item* will:

function without failure

under stated conditions

for a specified amount of time.



$R(t)=e^{-\lambda t}$, $\lambda=1/MTBF$?

Is constant failure rate really appropriate?

item *– an all-inclusive term to denote any level of unit (e.g. component, system, etc)*

e.g. Red Storm
"Intended Function"

Sandia National Laboratories

Red Storm is a *production* supercomputer, whose function is manifested via the following services:

Service Name	Description
login	Users can log in to the system.
compile	Users can compile applications.
job	Batch and interactive jobs work (submission, wait, shell-execution, application-execution, and cleanup [1]) work correctly, as are all batch queue functions (jobs can be submitted, queried, removed, and are being appropriately scheduled and executed).
io	Users and jobs can utilize the high performance file system.
scale	At least a certain number of nodes are up (e.g. 95% of the nodes in the section).

Table 1: Critical System Services

The system is…

- **"up" = all the above services are working.**
- **in "degraded" mode = a useful subset of the above are working.**
- **"down" = none of the above services are working.**

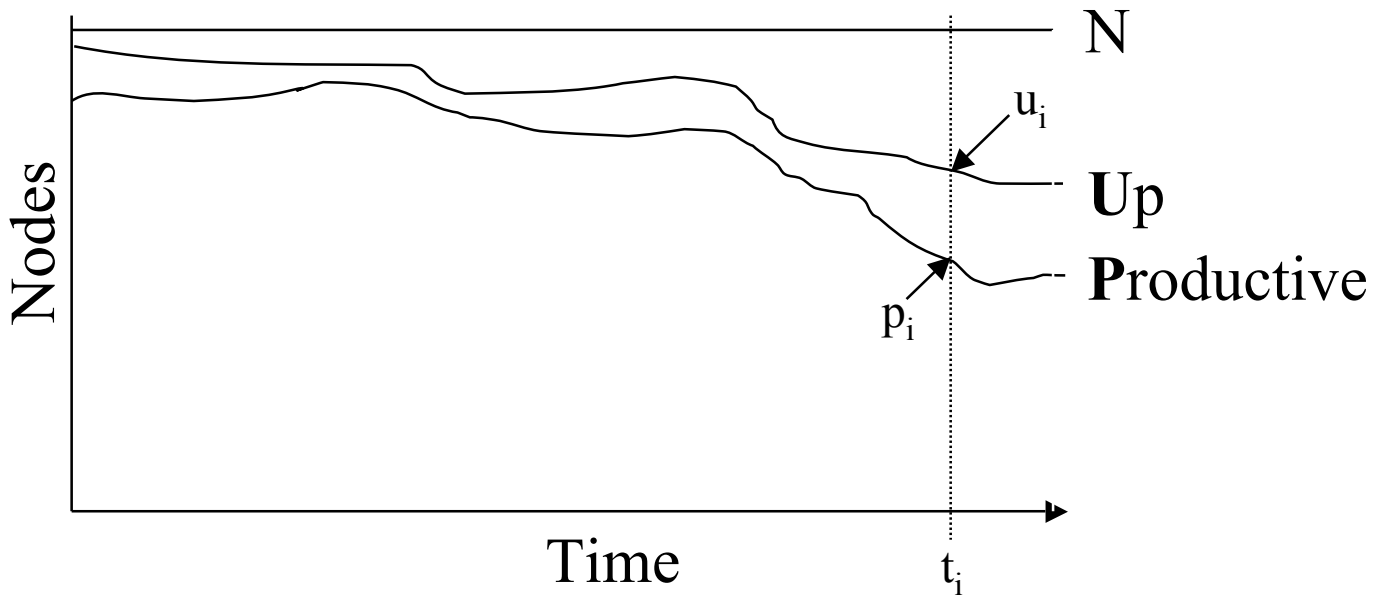
"Service Interrupt" = an interruption in any of the above services.

"System Failure" = an event requiring that the *system* (the majority of components) enter a downtime status before any component may enter a productive status.

= the *system* must go down before it can come up.

e.g. Red Storm

Detailed State Criteria



Item	State	Variable	Value
nodes	up	u_i	= SELECT COUNT(processor_id) FROM processor WHERE status='up';
	productive	p_i	= SELECT COUNT(DISTINCT processor_id) FROM partition_allocation;
	standby	s_i	$= u_i - p_i$
	downs	d_i	$= (u_i - u_{i+1}) > 0\,?\,(u_i - u_{i+1})\ :\ 0$ (an estimate only - see text!)
jobs	interrupted	j_i	= SELECT COUNT(partition_id) FROM job_accounting WHERE destroy_time>=t_{i-1}AND cleaned_by='ras';

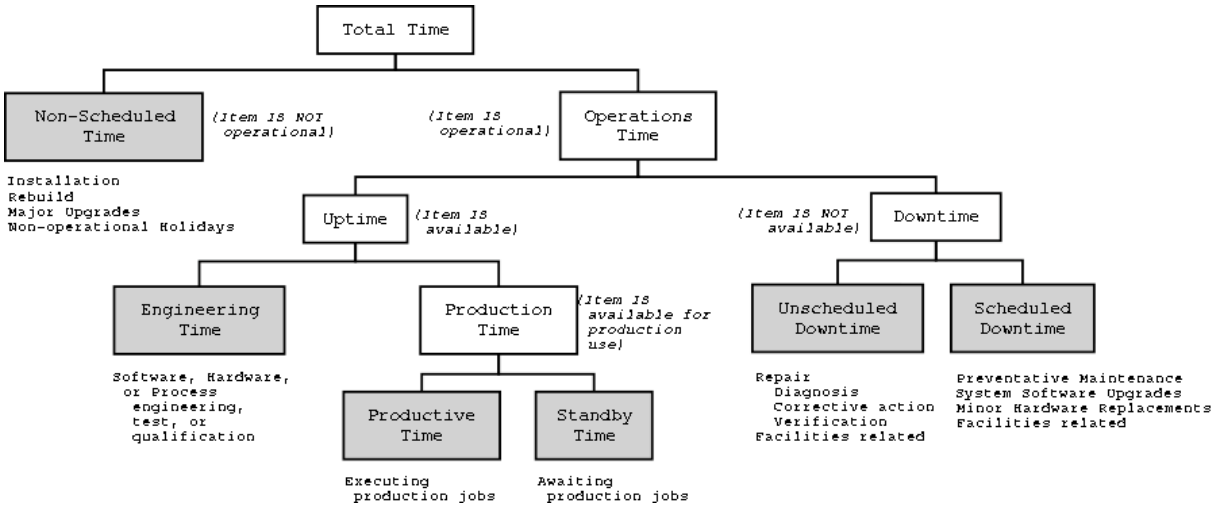
Table 2: Counting compute and login nodes at time t_i

See http://www.cs.sandia.gov/~jrstear/ras/

Availability [IEEE]

Sandia National Laboratories

The fraction of a time period that an item is in a condition to perform its intended function upon demand ("available").



$$Total\ \ Availability_{System}\ (\%) = \frac{uptime}{total\ time} * 100$$

$$Scheduled\ \ Availability_{System}\ (\%) = \frac{uptime - downtime}{scheduled\ uptime} * 100$$

Quantitative expectations exist!

See http://www.cs.sandia.gov/~jrstear/ras/

Next Steps

- **Ongoing discussion and revision - jump in!!!**

  I do NOT profess to have All The Answers;
  I DO seek to catalyze standardization.

- **Actual implementation on SNL platforms.**
  (Red Storm, Linux clusters)

- **Study failure and interrupt distributions.**
  (Towards selecting a model for reliability calculation,
  e.g. Poisson rather than Exponential?)

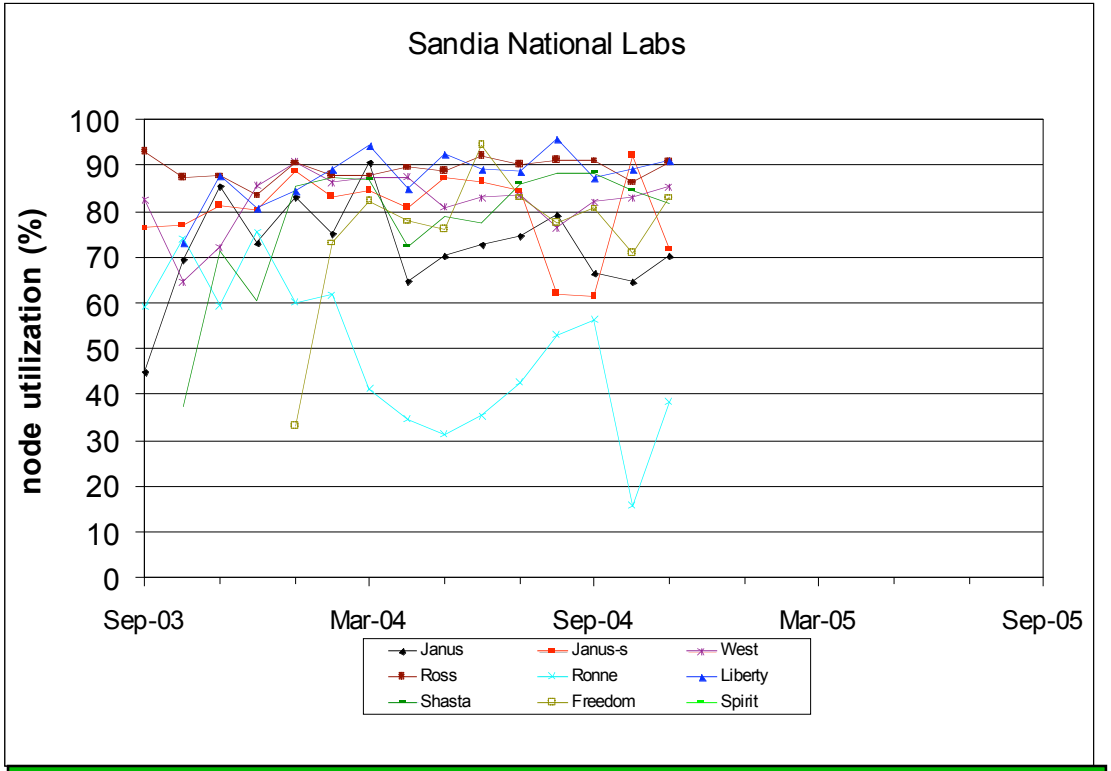
See http://www.cs.sandia.gov/~jrstear/ras/

Extra Slides…

Sandia National Laboratories

See http://www.cs.sandia.gov/~jrstear/ras/

Utilization
Common! RAS-meaningful?



High Utilization

High Availability

High Reliability (high MTBI and MTBF)

High Serviceability (low MTTR)

implies?

See http://www.cs.sandia.gov/~jrstear/ras/

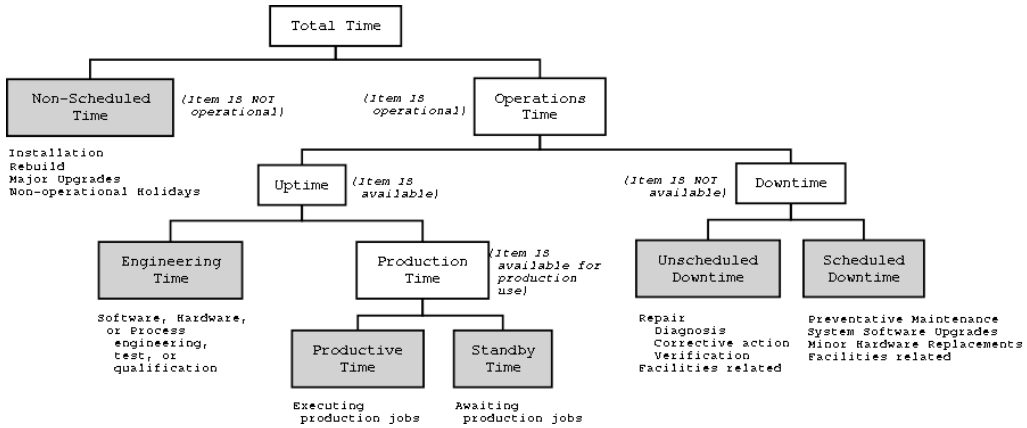
Utilization

Sandia National Laboratories

Non-RAS:

$$Production\ \ Time\ \ System\ Utilization\ (\%) = \frac{productive\ \ nodehours}{production\ \ nodehours} * 100$$

This has NO RAS information! It is entirely a function of workload and queuing configuration.



RAS:

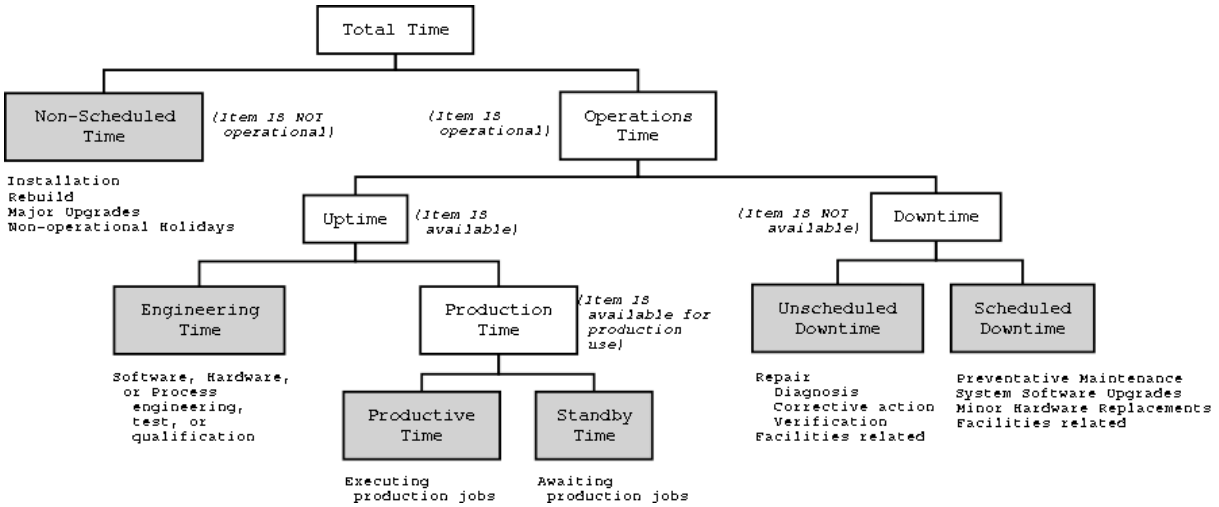
$$Total\ \ System\ Utilization\ (\%) = \frac{productive\ \ time * 100}{total\ \ time}$$

This IS a useful aggregate RAS metric. High total system utilization DOES indicate high reliability (MTBI, MBTF), availability, and serviceability (MTTR).

See http://www.cs.sandia.gov/~jrstear/ras/

Mean Time Between Service Interrupts

Service Interrupt – any event which disrupts full service to users (for any reason).



$$MTBI_{Service} = \frac{production\ \ time}{number\ of\ service\ interrupts}$$

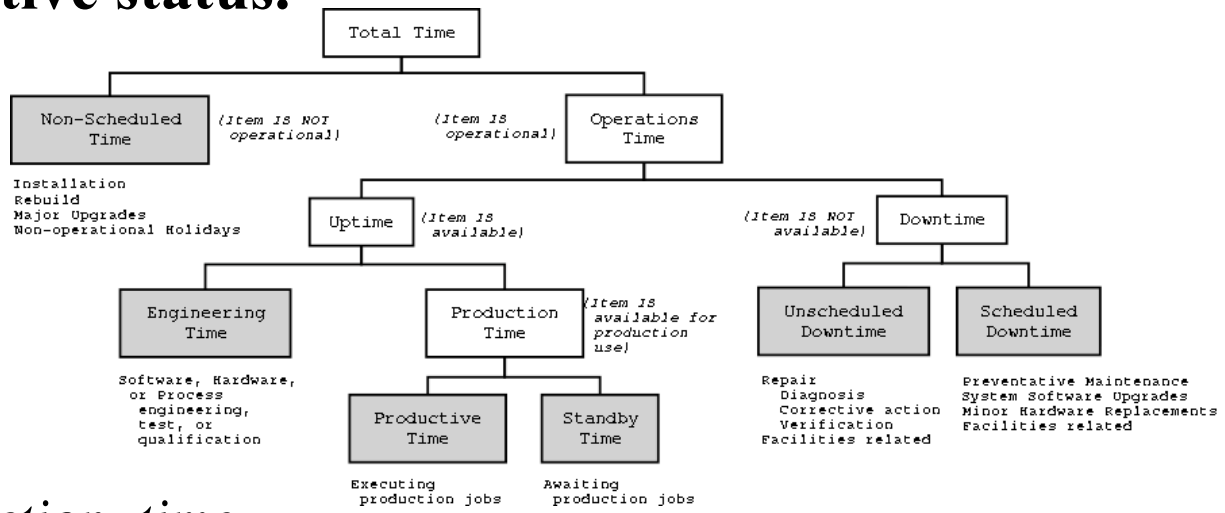
$$MNBI_{Service} = \frac{productive\ \ nodehours}{number\ of\ service\ interrupts}$$

← Includes workload information

See http://www.cs.sandia.gov/~jrstear/ras/

Mean Time Between Node Failures

Node Failure – an event requiring that the node (a component) enter a downtime status before it can enter a productive status.



$$MTBF_{Node} = \frac{production\ \ time}{number\ of\ node\ \ failures}$$

$$MNBF_{Node} = \frac{productive\ \ nodehours}{number\ of\ node\ \ failures}$$

← Includes workload information

See http://www.cs.sandia.gov/~jrstear/ras/

Costly!
Operations

Sandia National Laboratories

Excerpt from http://www.nersc.gov/nusers/status/AvailStats/:

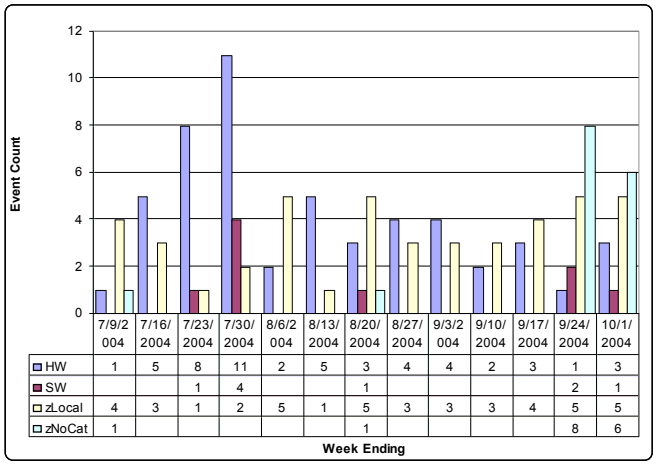
System Availability Details

FY05 - FEBRUARY 2005										
	Scheduled		Un-Scheduled			Overall	Sched	'MTBI	''MTTR	'''MTBF
System	H/W	S/W	H/W	S/W	Other	Avail %	Avail %	(Hours)	(Hours)	(Day:Hour:Min)
Parallel	99.61%	99.22%	99.87%	99.21%	100.00%	97.92%	99.07%	226	4.8	9 05:46
Storage	99.26%	99.39%	99.67%	99.91%	100.00%	98.23%	99.58%	207	3.4	8 13:00
File Servers	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%			
Math/Vis Servers	100.00%	99.82%	100.00%	99.85%	100.00%	99.66%	99.84%	1208	4.00	25 11:48

'**Mean Time Between Interruptions** = Total wall clock hours/total number of downtime periods
''**Mean Time To Restoral** = Total downtime hours/total number of downtime periods
'''**Mean Time Between Failures** = Total wall clock hours - Total downtime hours/Total downtime hours -1

Excerpts from LLNL ASC White "Six Sigma Report"

Estimated MTTI					
	week ending				
sector	item	8/27/04		9/3/04	
snow+white+frost+ice					
	# failures TOTAL	7		7	
	# failures HW	4	57%	4	57%
	# failures SW	0	0%	0	0%
	# failures LOCAL	3	43%	3	43%
	# nodes	624		624	
	# hours	168		168	
	# node-hours	104832		104832	
	MTBF (hr)	24		24	
	MTBF (hr/node)	14976		14976	



Serviceability

Sandia National Laboratories

Serviceability -

The probability that an item will be retained in, or restored to, *a condition to perform its intended function* within a specified period of time.

(A.K.A. “maintainability” in other communities)

Higher serviceability reduces the time spent in repair and maintenance (thus increasing availability and uptime ratio respectively)

See http://www.cs.sandia.gov/~jrstear/ras/

Repair vs Maintain?

Sandia National Laboratories

Repair – the act of restoring an item to a condition to perform a required function

Maintenance – the act of sustaining an item in or restoring it to a condition to perform a required function, usually during scheduled downtime.

MTTR – mean time to repair

MNTR - mean nodehours to repair (lost work potential)

MTTB - mean time to boot system

MTTR affects availability
(MTBI and MTBF affect availability and reliability)

See http://www.cs.sandia.gov/~jrstear/ras/

Exponential Random Variable

Components which exhibit a constant failure rate are appropriately modeled as exponential random variables, which have a time-to-failure pdf of $f(t)=\lambda e^{-\lambda t}$ (and thus a cdf of $F(t)=1-e^{-\lambda t}$), where λ is the constant "failure rate". Using this model:

$$\text{Reliability} = R(t)=e^{-\lambda t} \qquad \text{and} \qquad \text{MTBF} = 1/\lambda$$

A *system* MTBI of 50 hours (λ=0.02) would correspond to a reliability of 0.368. In other words, there is a 36.8% chance that the *system* will not experience an interrupt within 50 hours.

If we model Red Storm as a series *system* of 10,000 nodes which fail independently of each other, and we require a *system* MTBI of 50 hours, this corresponds to a per-node MTBI of 500,000 hours. If the requirement is reduced to a job running on 40% of the nodes, this corresponds to a node MTBI of 200,000.

See http://www.cs.sandia.gov/~jrstear/ras/